During the downward propagation, $(\theta_{i+1}, \Lambda_{i+1})$ becomes the initialization position/label pair and the 6-tuple

$$^*(d_i, \zeta_i, \Theta_{i+1}, \zeta_{i+1}, \Theta_{i+2}, \zeta_{i+2})$$

is subject to be refined by the model $\mathcal{M}_{i+1}$. The downward propagation terminates when either of the following criteria is met: the volume data bottom is reached or a marginal disk (L5/S1) is labeled. Upward propagation is analogical to the downward propagation.

The total labeling after upper/downer propagation can be assessed by geometry components of the optimal matches (see eqn. (3)) of models $\{\mathcal{M}_j\}$ to all detected disks {j} in the input dataset, excluding models optimized due to a dummy case:

$$Q^{\updownarrow} = -\frac{1}{|\{\mathcal{G}_{\tau_j^*}\}|}\sum_j \|\mathcal{G}_{\tau_j^*} - \overline{\mathcal{G}}_j\| \tag{4}$$

2.6. Finalization

Assessing Multiple Initializations: Labeling results from eventual multiple initializations (section 2.3.2) are compared by total labeling qualities (see eqn. (4)). Labeling with the maximal total labeling quality $Q^{\updownarrow}$ becomes the final one.

Vertebra Labels by Interpolation: The model matching framework delivers positions of intervertebral disks. Vertebral body positions and labels are obtained by linear interpolation between adjacent disks.

2.7 Results

By applying the method set forth above to the example given in FIG. **5**, the intervertebral disk T12/L1 in the spine image is determined as an initialization disk, i.e. an initial segment, of the spine and is labeled accordingly with "T12/L1" (see FIG. **5***d*).

Subsequently, as shown in FIG. **5***e*, model matching starts with a model of a spine segment considering properties of three intervertebral disks and two vertebrae around the initialization disk T12/L1 corresponding to the middle disk **25** shown in left part of FIG. **4**.

After repetitive propagation of model matching to further segments of the spine, intervertebral disks from L2/L3 to T1/T2 were detected and accordingly labeled in the image as shown in FIG. **5***f*.

FIG. **6** shows an example of a full-spine image dataset which has been correctly labeled by a method according to a preferred embodiment of the present invention. As apparent from the figure, the vertebrae represented in the image are annotated with respective spine labels Cn, Tn and Ln from cervical vertebra C3 to lumbar vertebra L5.

FIG. **7** shows further examples of labeled image datasets of parts of a spine. The segment of the spine represented in the left image features collapsed vertebrae and herniated disks; despite these unfavorable anatomical conditions, due to preferred embodiments of the invention respective vertebrae are correctly labeled from cervical vertebra C7 to lumbar vertebra L2. Same applies to the middle image featuring an extremely scoliotic spine segment, where the vertebrae are correctly labeled from thoracic vertebra T12 to lumbar vertebra L5. The right image shows a correctly labeled cervical image data set, labeled from C3 to T3.

3. Conclusion

In summary, by the method, apparatus and system disclosed herein both full and partial CT scans of a spine get labeled reliably and in a clinically reasonable time. With a recall of 95.5% the algorithm set forth above automatically labels a broad spectrum of input volumes including full spinal



columns, partial scans at different regions (cervical, thorax, lumbar), data with pathologies (e.g., scoliosis, osteoporosis, disk collapses), as well as data acquired by different vendors (like GE, Philips or Siemens) at a variety of spatial resolutions. An exemplary 512×512×5966 dataset labeled in 5.7 minutes evidences that the method scales very well.

To cope with all this variance in the input data, a framework was introduced based on following ideas: First, fast feature detection of target structures, mainly intervertebral disks and spinal canal, is refined by three-disk models. Second, a correct labeling is assured by learned structures to identify the initial disk at one of C7/T1, T12/L1, and L5/S1.

Preferably, the framework set forth above can be extended by disk orientation estimation. This can reliably be derived from the canal spline tangent. In fact, the canal features and spline fitting of our framework are robust so that it is also possible to investigate the Frenet frame (i.e., curvature and torsion) of the canal spline to quantify spine abnormalities.

Moreover, it is assumed within the algorithm set forth above that a standard atlas of the spinal column with 24 vertebrae, thought anomalies with one more or less vertebra exists. Such cases can be resolved by looking at the number of disk candidates relative to the reference structures (ribs, sacral foramina) in the disk initialization step. Furthermore, it is possible to train the fully automatic spine labeling framework on MR data and to extend the training data by more examples which cover a higher degree of anomalies and deviations in morphometry, e.g., spine scans from children.

The invention claimed is:

**1**. A method for labeling one or more portions of a spine in an image of a human or animal body, the method comprising the steps of:

a) matching a model of a spine segment with segments of the spine in the image by:
   - starting matching the model of the spine segment with an initial segment of the spine in the image, wherein the initial segment of the spine in the image is located at an initial position along the spine in the image; and
   - continuing matching the model of the spine segment with one or more further segments of the spine in the image, wherein the one or more further segments of the spine in the image are located at farther positions along the spine in the image, and the model of the spine segment relates to anatomical properties of one or more portions of the spine; and

b) labeling the one or more portions of the spine in the image in response to step a); wherein

an initial position of an initialization disk of the spine in the image is established by a disk profile corresponding to a string of region classes to which a set of disk candidates is mapped by classifying each disk candidate of the set of disk candidates to a region class or a region transition uncertainty; and

the disk profile is matched to a full spine profile and multiple initialization disk candidates, which result from the region class or the region transition uncertainty in the disk profile, are resolved by repeating the labeling step.

**2**. The method according to claim **1**, wherein the farther positions along the spine correspond to positions propagating from the initial position along the spine.

**3**. The method according to claim **1**, wherein the one or more portions of the spine in the image correspond to one or more vertebrae and/or intervertebral discs of the spine in the image.

**4**. The method according to claim **1**, wherein the model of the spine segment relates to anatomical properties of two to five vertebrae and/or intervertebral discs of the spine.